NOVEL INTRAOSSEOUS DEVICE PERFORMANCE AND LONGEVITY IN A GOAT MODEL (*CAPRA HIRCUS*)

A Thesis

by

ERIN ELIZABETH JACKSON

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Laboratory Animal Medicine

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Approved by:

Chair of Committee,	Karen Snowden
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Head of Department,	John August

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ABSTRACT

Novel Intraosseous Device Performance and Longevity in a Goat Model *(Capra hircus).* (December 2010)

Erin Elizabeth Jackson, D.V.M., Kansas State University

Chair of Advisory Committee: Dr. Karen Snowden

Two studies were performed to assess the function and longevity of a novel intraosseous (IO) catheter device. For the initial study, nine animals were assigned to three study groups. The first group received a 25 mm intraosseous device within the proximal humerus, the second group within the proximal tibia, and standard jugular catheters were placed in the final control group. Serial aerobic and anaerobic blood cultures were collected from jugular veins at day zero, then every third day while devices remained in use. Radiographs were obtained immediately after placement and again after removal of all IO devices. Goats were observed for overall clinical condition and lameness associated with catheter sites, and catheters were evaluated for patency and proper positioning. IO devices in the tibia remained in for less time than those in the humerus. Blood cultures in this study showed growth of *Bacillus*, *Staphylococcus*, and one colony within the genera *Brachyacterium* or novel *Dermabacteraceae*. Catheters also showed growth of *Bacillus*, as well as a single colony of *Micromonospora chalcea*. No animals in either IO group exhibited radiographic evidence of resulting damage or structural change within surrounding bone. In study two, eighteen goats were assigned

to two study groups (25 mm intraosseous device within the wing of the ilium, or 45 mm catheter in the proximal humerus). Blood for serial aerobic and anaerobic blood cultures and CBC were collected from jugular veins at day zero, then every second day thereafter while devices remained in use. All clinical monitoring and removal criteria were identical to study one. Catheters in the ilium remained in significantly less time than those in the humerus. Several animals in the proximal humerus group demonstrated moderate lameness following removal. One goat developed an abscess near the insertion site and showed radiographic evidence of periosteal bone growth. Serial cultures showed growth of *Bacillus*, *Streptococcus*, *Staphylococcus*, and *Enterococcus*. Bloodwork indicated mild elevations of white blood cells from baseline in some cases. Our study indicated that catheters may remain safely in place for greater than 24 hours, but that animals should be closely monitored for negative side-effects for several days during the post-removal period.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Snowden, for her unfailing patience and support, and my committee members, Dr. Gresham and Dr. Barhoumi Mouneimne, for their guidance throughout the course of my research. I would also like to thank Dr. Ashley and his staff at the Veterinary Medical Park for their assistance with the planning, technical, animal, and clinical support during all phases of the project. Thank you to Dr. Ficht and his lab group for allowing the use of their animals for the second study. In addition, much gratitude to Drs. Budke and Cohen for their statistical assistance.

I also want to extend my appreciation to the Vidacare Corporation, who provided me with indwelling catheter equipment and devices for the research. Finally, thanks to the Texas A&M Department of Veterinary Pathobiology and the Comparative Medicine Program for their funding of the studies.

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1. INTRODUCTION: INTRAOSSEOUS CATHETER USE IN HUMAN AND VETERINARY MEDICINE

Intravenous administration of fluids and medication is a crucial component of emergency medical case management. However, venous access is often extremely difficult to obtain in severely compromised patients. A cutdown procedure can be time-consuming and difficult for those inexperienced with the technique, and ultimately still may not succeed in gaining intravenous (IV) access during severe hypovolemia. The spectrum of drugs that may be given via the endotracheal route is limited, and their rate of distribution may be variable[33,38,39]. Also, the endotracheal route is obviously not an option for fluid replacement. In such instances where IV access is not readily accessible, intraosseous (IO) catheterization may serve as a reliable, life-saving alternative. This technique is frequently used in veterinary medicine, particularly in pediatric and exotic animal species. In veterinary medicine, the most common locations for intraosseous catheterization are the proximal humerus, proximal tibia, wing of the ischium, iliac crest, and the proximal femur[19,56]. While a number of studies have been performed on efficacy and potential applications of IO catheters in several veterinary species, including dogs, swine, and goats[5,12,18,30,45,46], there are limited data regarding use over an extended time period. It is generally recommended that IO catheters be removed as soon as venous access is attainable. However, it is conceivable that complications or other factors may arise, necessitating the use of an IO cannula for longer than anticipated.

This thesis follows the style of Comparative Medicine.

These devices have also gained a renewed interest within the human emergency medical community. While IO access has been most commonly utilized in human pediatrics, more recent attention has been given to its potential for use in adult emergency care and for military special operations.

Several devices have been introduced for IO catheterization, including the EZ-IO® (Vidacare, San Antonio, TX). This high-powered drill allows for control and minimal tissue damage, and may be placed at multiple anatomic sites with or without the use of local anesthetics. The EZ-IO® comes in several sizes, and is currently approved by the FDA for 24 hour use in the human tibia and humerus[25]. These needles are quickly situated, and several studies have shown that use of these devices and their proper placement are easily learned regardless of experience level[2,6,11,31,35]. The EZ-IO® has recently become available for use in veterinary medicine. We feel that in addition to the more typical small animal veterinary uses, these automatic drills may prove quite useful in large animal species of all ages, where manual placement of an intraosseous catheter may be difficult and time consuming. Our aim, therefore, was to evaluate the extended safety and efficacy of these devices for potential implications in large and small animal practice.

2. MATERIALS AND METHODS

2.1. Study One

Nine young adult domestic goats (*Capra hircus*) weighing between 27 kilograms and 40 kilograms were determined to be normal by physical examination (Texas A&M Veterinary Medical Park, College Station, TX, USA). All goats were housed in groups of three within approved laboratory animal facilities for the duration of the study, and used under a protocol approved by the Texas A&M Institutional Animal Care and Use Committee. Animals were assigned to one of three groups (IO device in the proximal tibia, IO device in the proximal humerus, or jugular catheter). Catheters (25 mm) utilized in this study were labeled for use in human patients 40 kilograms or greater in weight. Thus the six goats who most closely met the weight criteria were then randomly assigned to receive an indwelling device, either within the proximal tibia (n=3) or proximal humerus (n=3). The remaining three animals received a jugular catheter.

An intramuscular injection of 0.22 mg/kg xylazine (Butler Animal Supply, Dublin, OH) was administered, followed by intramuscular 11 mg/kg ketamine (Fort Dodge, Fort Dodge, IA) for induction of general anesthesia. Areas surrounding cannulation sites were clipped and prepared aseptically, and sterile technique was used for all device placements. Intraosseous devices were inserted according to manufacturer instructions, following aseptic preparation of the skin and a subcutaneous injection of 0.2ml of lidocaine (Sparhawk Laboratories, Lenexa, KS) immediately over the insertion point. The catheters were then placed through the skin and bone using the EZ-IO® high-

powered drill. Tibial devices were applied medially, placing the needle perpendicular to the bone, approximately one inch below the tibial tuberosity (Figures 1 and 2). Devices in the humerus were placed longitudinally within the head of the humerus. (Figures 3 and 4) In both, intramedullary placement was confirmed by firm seating and aspiration of blood and marrow contents. An EZ Connect® cap was then attached after removal of the stylet, and baseline radiographs were obtained for all IO sites prior to anesthetic recovery. Tibial IO devices were covered with a light wrap. Due to positioning, wrapping the devices in the humerus was not feasible. Jugular catheters were set in the classic fashion after skin preparation, using an 18g, 2" vinyl intravenous catheter (Emergency Medical Products, Waukesha, WI). Once blood flow was confirmed by aspiration, the catheter was secured to the skin using a small amount of skin glue and a 3-0 PDS suture (Butler Animal Health, Dublin, OH).

Approximately 3 ml of blood was collected from the jugular veins of all animals for baseline aerobic and anerobic cultures. Samples were submitted to the Texas Veterinary Medical Diagnostic Laboratory (TVMDL, College Station, TX) in 20 ml pediatric soy tryptinase blood culture media (Becton, Dickinson and Co, Sparks, MD). After flushing the catheter with 3 ml of 100U/10ml heparin (American Pharmaceutical Partners, Inc, Shaumburg, IL) saline (Butler Animal Health, Dublin, OH) flush as per manufacturer recommendations, the site was covered with a light wrap and the animal allowed to recover.

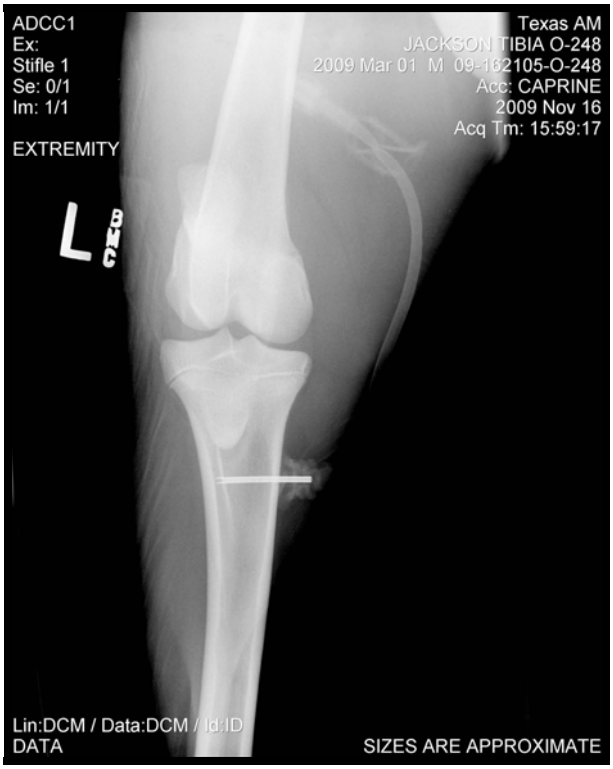

Figure 1. Radiographic view (caudal aspect) of proximal tibial intraosseous catheter placement.

Figure 2. Medial view of proximal tibial intraosseous catheter in left leg.

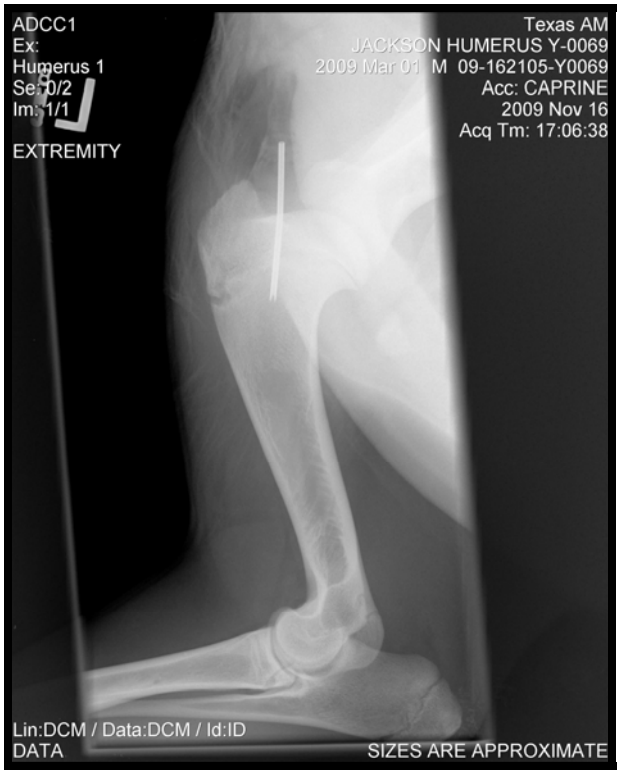

Figure 3. Radiographic view (lateromedial) of proximal humerus intraosseous catheter placement.

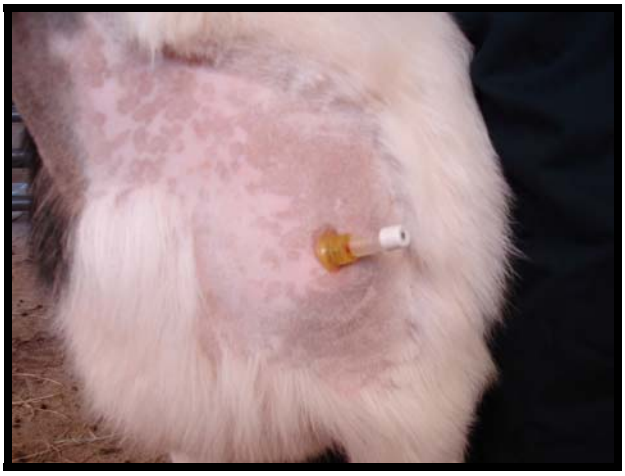

Figure 4. Lateral view of proximal humerus intraosseous catheter in the left leg.

Throughout the duration of the study, animals were observed at least twice daily by study personnel for overall condition, appetite, device-associated lameness, or any redness or swelling at the catheter sites. Each day, rectal temperatures were obtained and all catheters were evaluated for patency, as well as for firm seating within the bone. The ability to aspirate enough blood for culture through the cannulations varied among animals, therefore, all samples were collected from the jugular veins for consistency. Blood collection was performed every third day while catheters remained in place. Upon manual removal of IO devices by study personnel, catheters were submitted to TVMDL for aerobic and anaerobic culture. All goats with IO catheters still in place at the time of failure also underwent a second general anesthesia (0.22 mg/kg xylazine IM and 11mg/kg IM ketamine) for removal and follow-up radiographs.

Any catheters not flushing easily due to clogging or poor positioning were removed immediately. Other criteria for removal included: temperature exceeding 103.1ºF for greater than 24 hours, pain or lameness associated with the device, excessive redness, swelling, or discharge around insertion sites, and inappetance, lethargy, or other behavioral changes. Animals showing any of the aforementioned clinical signs were administered appropriate antibiotics (long-acting ceftiofur or tulathromycin) and/or analgesic medication (phenylbutazone) as needed, and all animals were placed on observation for 24-48 hours. After confirmation of good health status, goats were then returned to regular pasture housing.

2.2. Study Two

Eighteen young adult domestic goats (*Capra hircus*) weighing approximately 40 kilograms were determined to be healthy by physical examination (Texas A&M Veterinary Medical Park, College Station, TX, USA). All goats were housed in groups of three within approved laboratory animal facilities for the duration of the study, and used under a protocol approved by the Texas A&M Institutional Animal Care and Use Committee. Animals were assigned to one of two groups (25 mm IO device in the wing of the ilium or 45 mm IO device in the proximal humerus). Catheters utilized in this study were labeled for use in human patients 40 kilograms or greater in weight, and goats were randomly assigned to catheter locations.

An intramuscular injection of 0.22 mg/kg xylazine (Butler Animal Supply, Dublin, OH) was administered, followed by intramuscular 11 mg/kg ketamine (Fort Dodge, Fort Dodge, IA) for induction of general anesthesia. Areas surrounding cannulation sites were clipped and prepared aseptically, and sterile technique was used for all device placements. Intraosseous devices were inserted according to manufacturer instructions, following aseptic preparation of the skin and a subcutaneous injection of 0.2 ml of lidocaine (Sparhawk Laboratories, Lenexa, KS) immediately over the insertion point. The cannulas were then placed through the skin and bone using the EZ-IO® high-powered drill. Devices within the wing of the ilium were applied in the palpable dorsal crest, placing the needle parallel to the long axis of the bone (Figure 5) and radiographs were obtained to ensure proper placement. Devices in the humerus were placed longitudinally within the head of the humerus as in the first study.

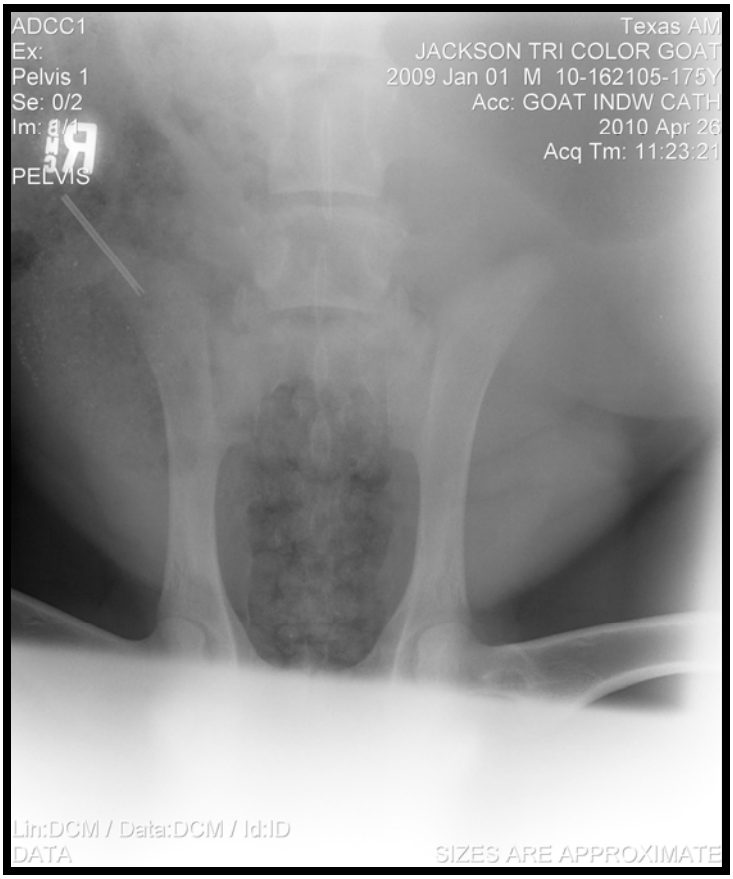

Figure 5. Radiographic view (ventrodorsal) of intraosseous catheter placed in the right ilium.

In both, intramedullary placement was confirmed by firm seating and aspiration of blood and marrow contents. An EZ Connect® cap was then attached after removal of the stylet. Since study personnel were proficient at application within the humerus following the initial study, additional radiographs were not utilized to check placement in the second group. Approximately 4 ml of blood was collected from the jugular veins of all animals for baseline aerobic and anaerobic cultures and CBC. Culture samples were submitted to the TVMDL in 20 ml pediatric soy tryptinase blood culture media. Blood samples for CBC were also submitted to TVMDL.

All other daily clinical monitoring, flushing, and criteria for removal were identical to the study one. Since no evidence of bony change was observed in the initial study, post-removal radiographs were obtained only in those animals showing evidence of lameness, swelling, or elevated temperature for more than 24 hours after removal of devices. Serum ELISA for Caprine Arthritis Encephalitis testing was also submitted to the TVMDL for two animals who showed persistent or intermittent lameness for greater than two weeks.

2.3. Statistical Analysis (Study Two)

Time to removal of intraosseous catheters placed in the wing of the ilium and the proximal humerus were analyzed using Kaplan-Meier time to failure curves and compared using the log-rank test. A p-value <0.05 was considered statistically significant. All analyses were carried out using Intercooled Stata version 11.0 software (Stata Corp., College Station, TX, USA).

3. STUDY ONE RESULTS

3.1. Proximal Tibia

Catheters in the tibia (n=3) were well tolerated, though some minor gait abnormalities were initially noted due to the placement of bandage material. Respective times of catheter removal for this group were at 18, 41, and 96 hours (Table 1). The catheter removed at 18 hours was found to be completely displaced during the first exam. No cultures were performed on this catheter, due to the high likelihood of environmental contamination beneath the bandage preventing accurate sample assessment. The second catheter was also found displaced under the bandage material approximately 41 hours after insertion, and again was not submitted for culture for the same reason. The final tibial catheter was removed after approximately 96 hours due to development of moderate lameness, though it was still patent and adequately seated at the time of removal. This is also the same animal, goat number 0100, who showed a mild degree of increased opacity within the stifle joint on post-removal radiographs (Appendix A). The goat was administered a long-acting intramuscular, broad-spectrum antibiotic at the time of removal, and had no further complications. The animal also displayed no further sign of gait abnormalities after anesthetic recovery. Due to the immediate resolution after removal of the device, the lameness was likely attributable to IO device bending and minor physical displacement. No further complications were noted in the animal in the following weeks.

Table 1. Study one survival times and removal criteria for intraosseous catheters in the jugular vein, proximal tibia, and proximal humerus

Animal	Catheter Type/Site	Time Removed (Hours)	Removal Criteria
163	Jugular	43	Non-patent
166	Jugular	96	End Study
161	Jugular	96	End Study
6600	IO Cath Tibia (25 mm)	18	Displaced
248	IO Cath Tibia (25 mm)	41	Non-patent
0100	IO Cath Tibia (25 mm)	96	Lameness/swelling
0250	IO Cath Humerus (25 mm)	67	Displaced
0096	IO Cath Humerus (25 mm)	83	Displaced
0069	IO Cath Humerus (25 mm)	88	Displaced

3.2. Proximal Humerus (25 mm Catheter)

Catheters in the humerus (n=3) were also well tolerated, though it was noted that external portions of devices within the humerus began to deviate from the original angle of placement within the first 24 hours. No immediate cause of the bending was noted during the exam periods, however, it may be assumed that the catheters were subjected to some degree of trauma due to the healthy, ambulatory nature of the animals in our study. Though all external portions of the device became progressively deviated from their original angle -- some up to 90°-- all catheters remained well seated in the bone and patent for at least 3 days. Catheters placed within the humerus (n=3) were removed due to resistance to flushing at approximately 67, 83, and 88 hours, respectively (Table 1). Animal number 0069, whose catheter was removed at 88 hours, developed mild swelling and purulent discharge at the catheter placement site in the 24 hours prior to removal, and was administered one intramuscular dose of a long-acting broad-spectrum antibiotic. No complications were noted on observation after removal, and the goat was released to regular pasture housingwithout further incident. No lameness resulting from device placement was observed in any animals within this group, and all animals remained bright, alert, and active throughout the study.

3.3. Jugular Catheters

One jugular catheter was removed from one of three goats in this experimental group after 43 hours due to the inability to flush effectively subsequent to kinking within the vessel. All other jugular catheters (n=2) remained patent until their removal,

coinciding with removal of the last remaining intraosseous devices at day four of the study (Table 1). All animals were returned to their normal pasture housing, and no sequelae to the catheter or device placement at any site were noted on visual exam in the weeks following removal.

3.4. Radiographs (Study One)

Radiographs were taken of all animals assigned to both initial intraosseous groups immediately after placement. They were taken again immediately after manual removal or unintentional displacement of the devices. All radiographs taken immediately after introduction of intraosseous catheters confirmed adequate placement, and did not show any evidence of damage to surrounding bone. Those taken following removal or dislocation of the devices also revealed healthy bone in most animals, with no evidence of fractures or other damage acquired during use of the devices (Appendix A). One animal with a tibial catheter, goat number 0100, showed mildly increased opacity within the stifle joint. This was the same animal whose catheter was removed due to lameness, but recovered fully (Table 1).

3.5. Culture (Study One)

Baseline blood cultures in the first study for animal numbers 166, 161, and 6600, were found to be negative for aerobic, anaerobic, and obligate anaerobic growth (Appendix B). Three baseline cultures for goat numbers 0100, 0096, and 0069 showed growth of an aerobic *Bacillus* species. The remaining three cultures in goat numbers 163,

0248, and 0250 showed combinations of *Bacillus* sp., *Micrococcus*, *Corynebacterium*, alpha-hemolytic *Streptococcus* sp., and coagulase negative *Staphylococcus* sp. Blood culture at day three showed one negative culture (goat 0250). Animal numbers 161, 0100, 0096, and 0069 again showed growth of a *Bacillus* species, animal 166 showed growth of coagulase negative *Staphylococcus* species, and goat 163 was found to have one colony of branching, gram positive rod of an unknown significance. Supplemental gene sequencing on this organism identified it as either belonging within the genera *Brachyacterium* or as a novel *Dermabacteracea* species. Catheters submitted for cultures after removal on animals 0100 and 0069 showed growth of *Bacillus* sp. One catheter from goat 0100 also showed a small amount of mixed bacterial growth, likely due to environmental contaminants. Cultures from goat 0250 grew one colony of a gram positive, branching rod. Supplemental gene sequencing identified the colony to be *Micromonospora chalcea.* No anaerobic or obligate anaerobic growth was noted among samples at any time point.

4. SECOND STUDY RESULTS

4.1. Wing of the Ilium

Catheters (25 mm) placed in the crest of the ilium (n=9) were well tolerated by all animals. However, eight of the devices became displaced within the first 24 hours (Table 2). One catheter remained in place for approximately 43 hours, until it also became displaced and required removal (goat 250). No animals in this group showed any lameness, swelling, or other clinical signs associated with the devices. No significant abnormal values were noted on CBC analyses in any goats in this experimental group (Appendix C)

4.2. Proximal Humerus (45 mm Catheter)

Similar to the study one, catheters were placed in the proximal humerus in a total of n=9 animals, but using a longer 45 mm catheter length. The catheters in the humerus were well tolerated, but began to deviate from the original angle of placement within the first 24 hours. The majority of the catheters remained patent for several days, with respective removal times of approximately 22, 31, 46, 46, 48, 94, 95, 100, and 100 hours (Table 2).

Table 2. Study two survival times for 45 mm intraosseous catheters in the proximal humerus and 25 mm IO catheters in the wing of the ilium

Animal	Catheter Type/Site	Time Removed (Hours)	Removal Criteria
87	IO Cath Humerus (45 mm)	22	Non-patent
07	IO Cath Humerus (45 mm)	31	Lameness/swelling
29	IO Cath Humerus (45 mm)	46	Non-patent
124	IO Cath Humerus (45 mm)	46	Non-patent
132	IO Cath Humerus (45 mm)	48	Non-patent
34	IO Cath Humerus (45 mm)	94	Non-patent
137	IO Cath Humerus (45 mm)	95	Lameness/swelling
131	IO Cath Humerus (45 mm)	100	Lameness/swelling
88	IO Cath Humerus (45 mm)	100	Lameness/swelling
0100	IO Cath Ilium (25 mm)	16	Fell out
299	IO Cath Ilium (25 mm)	16	Fell out
0099	IO Cath Ilium (25 mm)	16	Non-patent
298	IO Cath Ilium (25 mm)	19	Fell out
0069	IO Cath Ilium (25 mm)	19	Fell out
248	IO Cath Ilium (25 mm)	22	Fell out
0096	IO Cath Ilium (25 mm)	27	Fell out
175	IO Cath Ilium (25 mm)	30	Fell out
250	IO Cath Ilium (25 mm)	43	Fell out

4.3. Clinical Observations and Adverse Findings for Catheters in the Humerus

Subjectively, the 45 mm catheters appeared to be slightly more resistant to bending than the 25 mm needles, however, additionally appeared to cause more soft-tissue swelling around the insertion site following removal. Also, in this portion of the study, four of the 45 mm catheters were removed due to mild to moderate lameness in animal numbers 137, 131, 34, and 88. These four animals were administered appropriate antibiotics and analgesics. Follow-up radiographs were obtained on the four animals showing signs of discomfort or lameness for greater than 72 hours (goat numbers 29, 137, 131, and 134). Images indicated that swelling was confined to the soft tissue surrounding the insertion site, and no significant bony changes were noted in two of these four animals. Goat number 137 was noted to have a small bony defect at the site of insertion on radiographs (Appendix A), and remained intermittently lame for nearly three weeks. CBC showed normal white blood cell counts (Appendix D), and serum ELISA testing for Caprine Arthritis Encephalitis was negative. Subsequent follow up radiographs after approximately two weeks showed good healing of the area and resolution of soft tissue swelling, and the goat recovered fully.

A fourth animal, however, showed minimal improvement with clinical therapy (goat 29). This goat's catheter was removed on day two due to non-patency. Approximately two days later the goat developed a fever, swelling in the shoulder area, and became lame. Antibiotics were administered and the fever resolved completely, but approximately one week after catheter removal, an abscess developed dorsal to the original catheter insertion site. The abscess was drained and flushed, and culture showed

growth of *Arcanobacterium pyogenes* and *Staphylococcus aureus*. The animal was subsequently treated with five days of Procaine Penicillin G at 25,000 units/kg (Agripharm Products, Westlake, TX). Follow-up radiographs showed periosteal new bone and sclerosis around the glenoid/supraglenoid tubercles and greater tubercle of the humerus, as well as a lucency within the cranial glenoid/coracoid process (Appendix E). These findings were suggestive of possible infectious periostitis and osteomyelitis. CBC at that time showed a normal white blood cell count, and temperature remained normal. Serum ELISA testing for Caprine Arthritis Encephalitis was negative. An additional five days of antibiotic therapy was administered, as well as low dose dexamethazone 0.1 mg/kg.

4.4. Statistical Results

Time to removal of intraosseous catheters placed in the wing of the ilium and the proximal humerus were visualized using Kaplan-Meier time to failure curves and compared using the log-rank test (Figure 6). Time to failure was significantly longer for intraosseous catheters placed in the proximal humerus versus the wing of the ilium ($p=0.0008$).

Kaplan-Meier time to failure analysis for 25 mm IO catheters in the ilium and 45 mm IO catheters in the proximal humerus

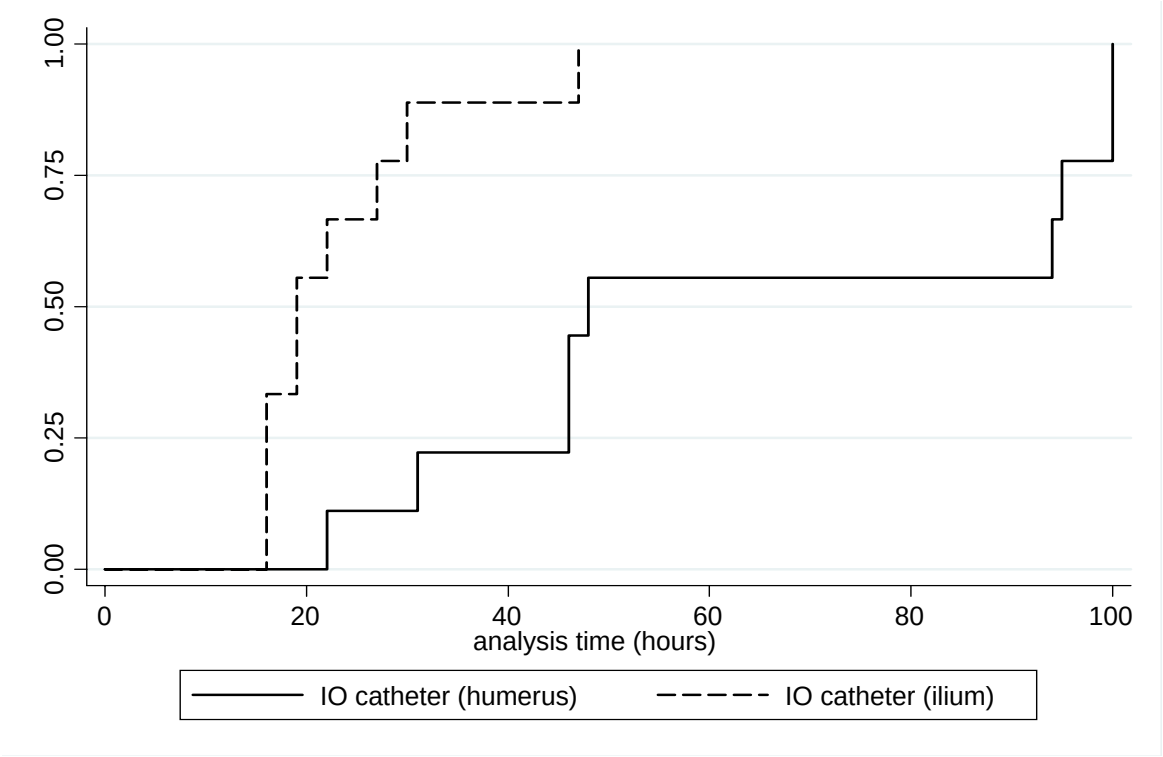

Figure 6. Kaplan Meier failure functions for 45 mm interosseous catheters placed in the humerus (n=9) and 25 mm intraosseous catheters placed in the wing of the ilium (n=9).

4.5. Radiographs (Study Two)

Four animals receiving 45mm catheters in the humerus had evidence of some soft tissue swelling surrounding the insertion site in follow-up radiographs (goat numbers 29, 131, 137, and 34)(Appendix A). This was not an unexpected finding, and was visible or palpable during examination. One other animal in within this group, goat number 137, showed a small defect at the insertion site that healed well radiographically in the following weeks. Goat number 29 demonstrated persistent lameness, despite antibiotic and analgesic therapy, and follow-up radiographs indicated development of early stage periostitis and osteomyelitis.

4.6. Culture (Study Two)

In the second study, all baseline cultures were negative (Appendix F). No catheters in the ilium remained past 24 hours, and so no further blood cultures were submitted for these animals. Also, no catheters were submitted from the ilium due to self displacement and the high likelihood of excessive environmental contamination.

In the nine goats with catheters in the humerus, four blood cultures were submitted on day two of the study, and three of these (animal numbers 131, 34, and 88) showed growth of *Bacillus* species. In the two samples that were submitted on day four, goat 131 showed growth of a gram positive rod, and goat 88 had no growth. However, animals having positive blood and/or catheter cultures were not necessarily those who appeared lame at any point in the study, and vice versa, so it is likely that growth may have been due to environmental contamination during collection. Catheters from the humerus submitted over the course of the experiment showed growth of *Bacillus cereus*, α-hemolytic *Streptococcus*, *Staphylococcus aureus*, and *Enterococcus* sp. For the goat who developed an abscess and radiographic evidence of osteomyelitis after removal (goat 29), neither of the bacteria cultured from the abscess were present in blood or catheter culture. Growth noted on blood cultures was likely attributable to environmental and/or skin contaminants acquired during the blood collection procedure or removal of IO devices.

5. DISCUSSION

In general, the intraosseous devices were well tolerated by the animals within study one, and those in the humerus and tibia were functionally similar to jugular catheters. Most remained functional for several days with few complications or notable long term health effects, with the exception of one goat. The majority of animals from the IO study groups exhibited no radiographic evidence of damage or structural change within the surrounding bone, again with the exception of one animal that showed a mildly increased opacity within the stifle joint. All other devices remaining in after the first day during study one were removed solely due to external deviation significant enough to affect overall patency.

In the study two, devices were also well-tolerated within the humerus and the wing of the ilium, though there was a significant difference ($p=0.0008$) in the time to failure of the catheters between the two groups when $p<0.05$. Catheters within the ilium became displaced much more quickly than all other locations, potentially making it a less useful location in clinical practice. Due to the mechanical trauma and bending that was noted with the sites in study one, it was our hope that catheters in the ilium might be subjected to less mechanical force during normal movements, and thus remain patent and in place for a longer time. Conversely, these were significantly less resilient in our study. This may possibly be due to a thinner cortex to seat the catheter in. Although a 45 mm needle could potentially be used in this site, initial placement would be more difficult due to the narrow space and angle of the marrow cavity, making it much more likely that the catheter would pass through the opposite cortex and not function properly.

Based on our results, the wing of the ilium would not be a recommended placement site in an ambulatory animal compared to a site in the humerus or tibia. It may still potentially be used in a recumbent patient if needed, but still may not be as resistant to displacement during movement or rotation of the animal.

We also observed a higher incidence of associated lameness and swelling in animals that received a 45 mm catheter in the humerus during the second study, and in one case, osteomyelitis. Radiographs showed that there was no significant bony change or evidence of fracture in nearly all of the goats, and swelling was predominantly soft-tissue and confined to the area immediately over the site of insertion. Also, aside from one animal, the majority of goats with swelling and lameness were those whose catheters remained in until an approximately four day timepoint. Eight of nine goats ultimately did well clinically, and no long term complications were observed in the following weeks after resolution. One animal developed an abscess and subsequent periostitis and osteomyelitis, which is a rare side effect also reported during use in human medicine. The exact reason for the increase in swelling and clinical signs in this group is not known, however, the longer needle size could potentially cause more soft tissue disturbance on insertion at the angle used. Also, since most swelling was noted following removal of the catheters, it may be partly attributable to the fact that removal of the 45mm needles required significantly more effort due to deeper seating in the bone, which could likely have resulted in more soft tissue disturbance at that time. Our experiment showed that this size catheter in the humerus is useful, but that side-effects in

this group were notable and should be taken into consideration when used in a practice setting.

In our study, the devices placed in the humerus appeared to remain functional and in place longer than those in the tibia or wing of the ilium, and all were comparable to the jugular catheter group in terms of initial usefulness for injectables in an ambulatory animal. In human medicine, however, automatic intraosseous devices are commonly used within the human tibia, and have also been utilized in some previous studies on animal models under surgical anesthesia with good results[12,14,15,21,29,42,53,54,55]. Studies in animal models have also demonstrated that adequate flow rates may be obtained using the tibia and malleolus, but that higher rates are attainable when using a location within the humerus and femur[54]. Animals in our study were healthy and active, so external portions of the IO catheters were likely subjected to significantly more movement and trauma than in the type of clinical situation where they would most likely be utilized. In our study, the thicker cortex of the humerus in the goats may have provided greater physical stability than the thinner cortex of the tibia. Also, the exiting angle of the cap in the humerus was such that it likely could withstand torque and forces better than the tibial device caps, which exit the skin at a 90° angle medially. However, all devices remaining in place were clinically comparable in terms of initial function, and could be easily utilized for administration of fluids and medications in an emergency clinical situation. One could consider the healthy status of the goats within this study a limitation. However, most of the IO devices place within the long bones remained functional and in place remarkably well.

The IO method would likely be used as an alternative emergency bridging method in compromised, hypovolemic, and possibly recumbent animals. In such cases, these devices would be exceptionally useful and provide a means of quick fluid, blood, or drug administration until venous access could be acquired at a later time. Proximal humerus devices in our study lasted three to four days, and one tibial device lasted four days prior to removal. In a recumbent or ill animal, these would likely remain patent for an even longer period of time, as they would not be subjected to the amount of activity and trauma placed on them by healthy animals. Though our study indicated that catheters may generally remain in safely for greater than the currently approved 24 hour time point, caution should be extended, as more side-effects were noted as time increased.

All animals remained bright, alert, and active throughout the study. Some animals did show growth on baseline and post-placement blood cultures, and on catheter cultures. However, the bacteria species that were isolated are ubiquitous within soil and within farm animal species. A total of two goats within the first study group were treated with antibiotics after removal of the device as a precaution for swelling or associated lameness, but all of the other seven animals remained healthy and active with no observed clinical sequelae whether or not positive cultures were obtained. Within the second study group (n=18), a total of four animals were treated with antibiotics after developing mild lameness and/or swelling. Those goats exhibiting clinical signs also did not show a particular correlation with changes noted on the CBC or culture growth results. While it is advisable to closely monitor any ill or immunocompromised patients

with either a jugular and/or intraosseous catheter in place, it is most likely that our positive cultures were due to skin and environmental contaminants during blood collection and device removal, though additional studies would be required to confirm this interpretation of the data.

The number of animals used for our studies was small, as this was an initial comparison of efficacy and assessment of tolerance and duration of use. However, we determined that with proper placement and management, these intraosseous devices may be left in place for greater than 24 hours (which the device is currently approved for during use in human medicine) with few complications. Future studies may explore use in a larger number of animals and/or clinically ill animals. One may also consider different anatomical locations that may potentially provide similar stability, but perhaps would be subject to less force by the animal's body weight during normal activity, or in a recumbent animal.

The EZ-IO® handheld drill is easy to use, and can be utilized properly after brief instruction. They are portable and generally take under 1 minute to prepare and insert with a 96%-100% successful placement rate[6,31]. Previous studies in human medicine have shown that the majority of nurses, medical students, physicians, and first responders are all able to successfully place these IO devices quickly within a clinical setting after a short training session describing its use[11]. This training approach could easily be extended to technicians and veterinarians within small and large animal clinical practice, and also in teaching institutions.

These devices also have a variety of potential applications for ambulatory large animal practice. The catheter may be placed with local anesthesia, reducing the need for risky general anesthesia in a compromised animal. Large volumes of fluid may be quickly administered with the aid of a pressurized system, and in most cases blood can be collected if needed, especially in young animals. Previous studies have shown that lab readings and cultures performed on blood collected from the bone marrow are clinically comparable to that of peripheral blood[1,7,9,20,22,34,55]. Care should be taken to avoid immature growth plates in pediatric patients, but some studies have noted that significant growth defects did not result from penetration of the plates in swine[10].

Agents administered into the intraosseous space are first absorbed into venous sinusoids, then travel rapidly into the central venous channel and systemic circulation[12,41,48,49], reaching the heart within 10 seconds. Studies have also shown that many drugs, such as glucose, lidocaine, calcium chloride, and epinephrine reach a peak effect within 30-45 seconds[33,44]. An added benefit of this system in emergency cases is that these sinuses remain open during shock or hypovolemic situations, unlike many peripheral veins[23,32,50]. Additional studies have shown that in most cases, medications and anesthetic administered at an intravenous dose via an intraosseous route have equal distribution and effect[4,9,21,26,28,29,33,37,42,44,45,52,53,55]. Some antibiotics, such as ceftriexone, may reach slightly lower serum levels when given IO[37], though are generally comparable. This may need to be taken into consideration if a loading dose of antibiotic is desired, as in cases of suspected sepsis or meningitis. In such situations, the highest recommended manufacturer dose may be warranted when being administered

intraosseously. In addition, intraosseous fluids and blood transfusions are equally as effective as those given intravenously[36,43].

Some contraindications to use are infection, injury, and cellulitis over the insertion point, or if there is damage or fracture of the bone intended for use[13,55]. The use of intraosseous devices is also not recommended in patients known to be bacteremic. While most fluids and medications may be given IO, there are some known to cause damage to bone marrow. Very alkaline or hypertonic solutions should be diluted prior to administration to help avoid medullary damage and subsequent development of osteomyelitis. Additionally, several human cases of osteomyelitis have been documented after hypertonic solutions were administered IO in children, including 5% sodium chloride (NaCl), which may cause marrow necrosis and some damage to the endosteum[3,30]. Sodium bicarbonate injections have also been noted to cause mild inflammatory changes within the surrounding bone marrow cells[45,47] and minor increases in skeletal turnover[24]. Additionally, Dextran 70 can cause minor disruption of the medullary cavity.

Many of these clinical cases of osteomyelitis were observed in the late 1940's. The current percentage of resulting osteomyelitis in human patients is less than 0.6% of all cases[41], likely due to improvements in aseptic technique and antibiotic administration. There is also some concern about potential for fat and bone marrow pulmonary emboli after aggressive intraosseous infusion[17,32]. However, emboli may be found in traumatized patients with or without damage to bone, and most cases, these risks are often outweighed by the many benefits of IO cannulation in emergency situations. Complication rates are relatively low, though the devices should be monitored closely. Punctures in the opposite cortex and extravasation of fluids may result in decreased efficacy, pain, and compartmental syndrome after placement or with multiple attempts at cannulation[8,27,40]. Unintentional displacement is considered one of the most common complications associated with intraosseous catheters.

6. CONCLUSIONS

In summary, the IO devices are simple to use, portable, quickly placed, require minimal training to use, and have immense potential for use within many different veterinary settings when intravenous access is not immediately accessible. The automatic drill devices are useful in larger or adult bones where manual catheter placement may be difficult and time consuming. Several studies have shown no long term, negative sequelae in swine[10,24,51,53], and our initial study on a goat model further supports these previous findings. The EZ-IO® device in particular may be used with or without local anesthesia, saving valuable time and resources. Although venous access remains the gold standard for emergency drug and fluid administration, intraosseous devices provide a valuable alternative bridging technique for quick administration of potentially life-saving fluids and therapeutics in clinical and field settings.

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APPENDIX A

RADIOGRAPHIC INTERPRETATIONS (STUDY ONE):

Radiographs reviewed by Bunita Eichelberger DVM, MS, Dipl. ACVR

Note: The interpretation is of the radiographic studies provided. As 50% bone loss is required to be detected radiographically, subtle bone lesions (i.e. infection), may be occurring but is not radiographically detectable.

November 16, 2009

Goat Y-0069
Radiographic Findings: Left humerus. Open physes are expected for the age of the animal. A 5.2 cm catheter is inserted medial to the greater tubercle in a proximal to distal direction within the medullary cavity of the proximal humeral diaphysis; the catheter extends approximately 2.8 cm into the medullary cavity.
Radiographic Impressions: Adequate catheter placement. There is no evidence of implant failure, fractures or infection.

Goat Y-0096
Radiographic Findings: Left humerus. Open physes are expected for the age of the animal. A 6.2 cm catheter is inserted medial to the greater tubercle in a proximal lateral to distal medial direction within the medullary cavity of the proximal humeral diaphysis; the catheter extends approximately 3.0 cm into the medullary cavity.
Radiographic Impressions: Adequate catheter placement. There is no evidence of implant failure, fractures or infection.

Goat Y-6600
Radiographic Findings: Left tibia. Open physes are expected for the age of the animal. A 3.5 cm catheter is inserted in a cranial to caudal direction within the medullary cavity of the proximal tibia diaphysis. Bandage material surrounds the tibia.
Radiographic Impressions: Adequate catheter placement. There is no evidence of implant failure, fractures or infection.

Goat O-250
Radiographic Findings: Open physes are expected for the age of the animal.

Right Humerus. A 3.4 cm catheter is inserted in a cranial to caudal direction within the medullary cavity of the proximal humeral diaphysis. Bandage material surrounds the humerus.

Left Humerus. A 5.2 cm catheter is inserted medial to the greater tubercle in a proximal to distal direction within the medullary cavity of the proximal humeral diaphysis; the catheter extends approximately 3.2 cm into the medullary cavity.

Radiographic Impressions: Adequate catheter placement within the proximal humerus, bilaterally. There is no evidence of implant failure, fractures or infection.

Goat O-248
Radiographic Findings: Left tibia. Open physes are expected for the age of the animal. A 3.2 cm catheter is inserted in a cranial to caudal direction within the medullary cavity of the proximal tibia diaphysis. Tubing is identified external to the catheter.
Radiographic Impressions: Adequate catheter placement. There is no evidence of implant failure, fractures or infection.

Goat O-100
Radiographic Findings: Left tibia. Open physes are expected for the age of the animal. A 3.5 cm catheter is inserted in a cranial to caudal direction within the medullary cavity of the proximal tibia diaphysis. A T-port and tubing is identified external to the catheter.
Radiographic Impressions: Adequate catheter placement. There is no evidence of implant failure, fractures or infection.

November 17, 2009

Goat O-250
Radiographic Findings: The study is compared to the one made on November 16, 2009. Right humerus. The catheter is not visualized. A cylindrical lucency is identified within the medullary bone of the proximal humerus where the catheter was previously placed. There is no evidence of infection or fractures.
Left humerus. The portion of the catheter external to the proximal humerus is sharply angulated; the catheter remains similarly positioned without evidence of catheter retraction. There is no evidence of infection or fracture.

Goat Y-6600.
Radiographic Findings: Left tibia. The study is compared to the one made on November 16, 2009. The catheter is not visualized. There is no evidence of infection or fractures.

November 18, 2009

Goat O-248
Radiographic Findings and Impressions: Left tibia. The study is compared to the one made on November 16, 2009. The catheter is not visualized. A cylindrical lucency is identified within the medullary bone of the proximal tibia where the catheter was previously placed. There is no evidence of osteomyelitis or fractures. Soft tissue

swelling and gas opacities are identified within the soft tissues along the medial aspect of the proximal tibia; this may be secondary to catheter placement although edema, cellulitis or abscess cannot be excluded.

November 19, 2009

Goat O-250
Radiographic Findings and Impressions: Left humerus. The study is compared to the November 16 and 17, 2009. The catheter is retracted; approximately 1.5 cm remains within the humeral diaphysis. Subsequent images demonstrate complete removal of the catheter. A small elliptical mineral opacity is identified along the cranial margin of the humerus which may represent a small avulsed fragment that occurred during catheter placement. There is focal soft tissue swelling along the cranial margin of the humerus which may be associated with the previous catheter although edema, cellulitis or abscess cannot be excluded. There is no evidence of osteomyelitis.

November 20, 2009

Goat Y-0069
Radiographic Findings and Impressions: Left humerus. The study is compared to the one made on November 16, 2009. The catheter is retracted; approximately 1.6 cm remains within the proximal humerus. The external portion of the catheter is angulated and a T-port is identified attached to the catheter. Subsequent radiographic projections demonstrate complete removal of the catheter. There is focal soft tissue swelling along the cranial margin of the humerus which may be associated with the previous catheter although edema, cellulitis or abscess cannot be excluded. There is no evidence of osteomyelitis or fractures.

Goat Y-0096
Radiographic Findings and Impressions: Left humerus. The study is compared to the one made on November 16, 2009. The catheter has been removed. The cranial margin of the greater tubercle is irregular which is similar to the previous examination. There is no evidence of osteomyelitis or fractures.

Goat Y-0100
Radiographic Findings and Impressions: Left tibia. The study is compared to the one made on November 16, 2009. The catheter has been removed; cylindrical lucencies are identified within the proximal tibia diaphysis in the region of the previous catheter. In one of the projections, a catheter is identified within the soft tissues of the cranial tibia. There is soft tissue swelling and subcutaneous gas within the tissues surrounding the proximal tibia, especially along the cranial and medial aspects of the tibia. There is increased opacity within the stifle joint.

The soft tissue swelling may be associated with the previous catheter although edema, cellulitis or abscess cannot be excluded. Possible left stifle effusion; early septic arthritis cannot be excluded. There is no evidence of fractures.

RADIOGRAPHIC INTERPRETATIONS (STUDY TWO):

April 26, 2010

Goat: 248
Radiographic findings: Six views of the pelvis are available for review. The first four radiographs were made to evaluate for radiographic technique and positioning. Image #5 and image #6 were made after intraosseous catheter placement. An intra-osseous catheter has been inserted within the dorsal medial margin of the right ilial wing; focal gas opacities are identified surrounding the margin/tip of the catheter. A T. port has been placed on the external surface of the catheter.
Radiographic impressions: Adequate intraosseous catheter placement without apparent complications. The gas opacities surrounding the intraosseous catheter are most likely iatrogenic.

Goat: 175
Radiographic findings: Two views of the pelvis are available for review. An intraosseous catheter has been positioned along the cranial lateral margin of the right ilial wing with termination within the medullary cavity AP port extends from the external portion of the catheter. Osseous structures of the pelvis including sacroiliac joints, right and left coxofemoral joints are radiographically normal.
Radiographic impressions: Adequate intraosseous catheter placement without apparent complications.

Goat: 298
Radiographic findings: Three views of the pelvis are available for review. An intraosseous catheter has been positioned along the cranial lateral margin of the right ilial wing with termination into the medullary cavity. A T. port is positioned onto the external portion of the catheter. Osseous structures of the pelvis including sacroiliac joints, right and left coxofemoral joints are radiographically normal.
Radiographic impressions: Adequate intraosseous catheter placement without apparent complications.

Goat: 0069
Radiographic findings: Three views of the pelvis are available for review. An intraosseous catheter has been inserted within the dorsal medial margin of the right ilial wing. A T. port has been placed on the external surface of the catheter. Osseous structures of the pelvis including sacroiliac joints, right and left coxofemoral joints are radiographically normal.

Radiographic impressions: Adequate intraosseous catheter placement without apparent complications.

Goat: 250
Radiographic findings: Three views of the pelvis are available for review. An intraosseous catheter has been inserted along the cranial lateral margin of the right ilium with insertion into the medullary cavity. A T. port has been placed on the external surface of the catheter. Osseous structures of the pelvis including sacroiliac joints, right and left coxofemoral joints are radiographically normal.
Radiographic impressions: Adequate intraosseous catheter placement without apparent complications.

Goat: 0096
Radiographic findings: Three views of the pelvis are available for review. An intraosseous catheter has been inserted along the cranial lateral margin of the right ilial wing with termination within the medullary cavity. A T. port has been placed on the external surface of the catheter. Pelvic structures including sacroiliac joints, right and left coxofemoral joints are radiographically normal.
Radiographic impressions: Adequate intraosseous catheter placement without apparent complications.

Goat: 0100
Radiographic findings: An intraosseous catheter has been positioned along the cranial medial margin of the right ilial wing with termination into the medullary cavity. A T. port has been placed onto the external surface of the catheter. Osseous structures of the pelvis including sacroiliac joints, right and left coxofemoral joints are radiographically normal.
Radiographic impressions: Adequate intraosseous catheter placement without apparent complications.

Goat: 0099
Radiographic findings: Three views of the pelvis are available for review. An intraosseous catheter has been inserted along the lateral aspect of the right ilial wing with termination within the medullary bone. A T. port has been placed on the external surface of the catheter. Osseous structures of the pelvis including sacroiliac joints, right and left coxofemoral joints are radiographically normal.
Radiographic impressions: Adequate placement of intraosseous catheter.

Goat: 299
Radiographic findings: Five views of the pelvis are available for review. An intraosseous catheter has been inserted with positioning along the cranial and lateral margin of the right ilial wing. On the ventral dorsal views, the catheter appears to be external to the medullary cavity of the right ilium. Osseous structures of the pelvis including sacroiliac joints, right and left coxofemoral joints are radiographically normal. Open physes are expected for the age of the animal.
Radiographic impressions: Suspect malpositioned catheter. Recommend reinserting/repositioning catheter into the medullary bone of the right ilium.

Goat: 131
Radiographic findings: Five views of the right humerus are available for review. Radiographs were made after removal of a previously placed intraosseous catheter. An intraosseous catheter is not identified within the radiographic projections. An irregularly marginated bony defect is identified within the greater tubercle; small mineral opacities extend from the defect. A well-circumscribed lucency extends into the medullary epiphysis of the greater tubercle; a circular region of sclerosis is identified in the center of this lucency. The articular surface of the scapulohumeral joint is smooth and well aligned; soft tissue structures of the shoulder are radiographically normal.
Radiographic impressions: The focal osseous defect within the greater tubercle is most likely related to previous catheter placement. The focal lucency and sclerosis of the medullary bone may represent bone edema, osteomyelitis or infarction. Repeat radiographs are recommended in 7-14 days for further diagnostic evaluation.

Goat: 137
Radiographic findings: Four views of the right humerus are available for review. Radiographs were made after removal of a previously placed intraosseous catheter. An intraosseous catheter is not identified within the radiographic projections. An irregularly marginated bony defect is identified within the greater tubercle; small mineral opacities extend from the defect. The greater tubercle of the humerus is sclerotic. A well-circumscribed lucency extends into the medullary epiphysis of the greater tubercle; a circular region of sclerosis is identified in the center of this lucency. The articular surface of the scapulohumeral joint is smooth and well aligned. There is soft tissue swelling along the cranial and lateral margins of the scapulohumeral joint.
Radiographic impressions: A focal osseous defect within the greater tubercle is most likely related to previous catheter placement however the extent and sclerosis is suspicious for an incomplete fracture. The focal lucency and sclerosis of the medullary bone may represent bone edema, osteomyelitis or infarction. Differentials for the soft tissue swelling include edema, hemorrhage, hematoma, abscess, or cellulitis. Repeat radiographs are recommended in 7-14 days for further diagnostic evaluation.
Goat: 29
Radiographic findings: Four views of the right humerus are available for review. Radiographs were made after removal of a previously placed intraosseous catheter. An intraosseous catheter is not identified within the radiographic projections. An irregularly

marginated bony defect is identified within the greater tubercle; small mineral opacities extend from the defect. There is soft tissue swelling along the cranial and lateral margins of the scapulohumeral joint. The articular surface of the scapulohumeral joint is smooth and well aligned; soft tissue structures of the shoulder are radiographically normal.
Radiographic impressions: The appearance of the greater tubercle is most likely related to previous catheter placement with focal periosteal new bone suggestive of periostitis. Differentials for the soft tissue swelling include edema, hemorrhage, hematoma, abscess, or cellulitis. Repeat radiographs are recommended in 7-14 days for further diagnostic evaluation.

Goat: 34
Radiographic findings: Five views of the right humerus are available for review. Radiographs were made after removal of a previously placed intraosseous catheter. An intraosseous catheter is not identified within the radiographic projections. An irregularly marginated bony defect is identified within the greater tubercle. There is soft tissue swelling along the cranial and lateral margins of the scapulohumeral joint. The articular surface of the scapulohumeral joint is smooth and well aligned; soft tissue structures of the shoulder are radiographically normal.
Radiographic impressions: The appearance of the greater tubercle is most likely related to previous catheter placement. Soft tissue swelling; differentials include edema, hemorrhage, hematoma, abscess or cellulitis. Repeat radiographs are recommended in 7-14 days for further diagnostic evaluation.

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Goat: 137
Radiographic findings: Four views of the right humerus are available for review. The study is compared to the radiographs made on May 26, 2010. The previously described focal osseous defect within the greater tubercle is filling in with osseous callus; the greater trochanter margins are mildly sclerotic. The well-circumscribed lucency extending into the medullary epiphysis is static in appearance; there is preservation of the trabecular bone. There is less soft tissue swelling than on the previous examination.
Radiographic impressions: Resolving soft tissue swelling and healing defect within the greater tubercle. As the focal lucency and sclerosis of the medullary bone has not progressed, bone edema or infarction is possible; osteomyelitis is considered unlikely.

Goat: 29
Radiographic findings: Three views of the right humerus are available for review. The study is compared to the radiographs made on May 26, 2010. The previously described soft tissue swelling has improved. Periosteal new and sclerosis is identified surrounding the distal scapula including region of the glenoid and supraglenoid tubercle. Periosteal new bone is identified along the margin of the greater tubercle. The humeral head is sclerotic although scapulohumeral joint margins are smooth. A lucency is identified

within the cranial glenoid/coracoid process. The previously described defect within the greater tubercle is similar.
Radiographic impressions: Although there is resolving soft tissue swelling, the bony changes are suggestive of an infectious periostitis and osteomyelitis; septic arthritis cannot be excluded. Repeat radiographs are recommended in 5-7 days to follow progression of the osseous changes.

APPENDIX B

CULTURE RESULTS FOR CATHETERS IN THE JUGULAR VEIN

Animal	**Blood culture results**		**Removal time (hrs)**	**Removal Criteria**
	Day 0	**Day 3**		
163	-*Bacillus* sp. -*Micrococcus* sp. -*Brachybacterium* or novel *Dermabacteracea* sp.	n/a	43	Non-patent
166	No growth	Coagulase neg. *Staphylococcus*	96	End study
161	No growth	-*Bacillus* sp.	96	End study

CULTURE RESULTS FOR 25 MM CATHETERS IN THE PROXIMAL TIBIA

Animal	**Blood culture results**		**Catheter culture**	**Removal time (hrs)**	**Removal Criteria**
	Day 0	**Day 3**			
6600	no growth	n/a	n/a	18	Displaced
248	-*Bacillus* sp. -*Corynebacterium* -α-hemolytic *Streptococcus*	n/a	n/a	41	Non-patent
0100	-*Bacillus* sp.	-*Bacillus* sp.	-*Bacillus* sp. -mixed bact growth	96	Lameness

CULTURE RESULTS FOR 25 MM CATHETERS IN THE PROXIMAL HUMERUS

Animal	**Blood culture results** Day 0	Day 3	**Catheter culture**	**Removal time (hrs)**	**Removal Criteria**
0096	-*Bacillus* sp.	*Bacillus*	n/a	67	Displaced
0250	-*Bacillus* sp. -coagulase neg. *Staphylococcus*	no growth	*Micromonospora chalcea*	83	Displaced
0069	-*Bacillus* sp.	*Bacillus* sp.	*Bacillus cereus*	88	Displaced

APPENDIX C

DAY 0 CBC RESULTS: IO CATHETERS IN THE WING OF THE ILIUM

Animal		Day 0 Results
248	WBC	15000
	ANC	9000
	ALC	6000
175	WBC	7500
	ANC	4650
	ALC	2775
298	WBC	11500
	ANC	6900
	ALC	4255
0069	WBC	11800
	ANC	7198
	ALC	4366
250	WBC	19100
	ANC	12797
	ALC	6303
0096	WBC	14300
	ANC	11297
	ALC	3003
0099	WBC	14000
	ANC	10640
	ALC	3220
0100	WBC	16000
	ANC	10240
	ALC	5760
299	WBC	8300
	ANC	4731
	ALC	3403

Normal Ranges:
(WBC) Total WBC: 4000-13000/ul
(ANC) Abs Neutrophils: 1200-7200/ul
(ALC) Abs lymphocytes: 2000-9000/ul

APPENDIX D

DAY 0, 2, AND 4 CBC RESULTS: 45 MM IO CATHETER IN HUMERUS

Animal		Day 0 Results	Day 2 Results	Day 4 Results	Follow-up Results (day 25)
29	WBC	13300			11600
	ANC	6118			5104
	ALC	7182			6264
131	WBC	12100	14300	15000	
	ANC	7986	6149	5850	
	ALC	4114	7722	9000	
137	WBC	14600	17500		
	ANC	10512	9975		
	ALC	4088	7525		
34	WBC	17900	16800		
	ANC	13604	9912		
	ALC	3580	6216		
88	WBC	14300	20000	14500	
	ANC	10582	12400	9570	
	ALC	3432	6400	4495	
124	WBC	7340			
	ANC	1028			
	ALC	5138			
132	WBC	8870			
	ANC	6564			
	ALC	1951			
87	WBC	13100			
	ANC	4716			
	ALC	4454			
7	WBC	10500			
	ANC	6930			
	ALC	3360			

Normal Ranges:
(WBC) Total WBC: 4000-13000/ul
(ANC) Abs Neutrophils: 1200-7200/ul
(ALC) Abs lymphocytes: 2000-9000/ul

APPENDIX E

RADIOGRAPHIC VIEW OF POST REMOVAL PERIOSTITIS AND OSTEOMYELITIS

Radiographs (goat number 29) showing periosteal new bone and sclerosis around the glenoid/supraglenoid tubercles and greater tubercle of the humerus, as well as a lucency within the cranial glenoid/coracoid process. Findings were suggestive of possible infectious periostitis and osteomyelitis.

APPENDIX F

CULTURE RESULTS FOR 45 MM IO CATHETERS IN THE HUMERUS

Animal	Blood cultures			Catheter culture	Removal after	Removal Criteria
	Day 0	Day 2	Day 4			
29	No growth	n/a	n/a	-*Bacillus cereus* -A-hemo Strep	<48hrs (2d)	Non-patent
131	No growth	*Bacillus* sp.	Gm + rod	*Enterococcus* sp.	96hrs (4d)	Lameness
137	No growth	No growth	n/a	- *Staph aureus* -A-hemo *Strep*	<96 hrs (4d)	Lameness
34	No growth	*Bacillus* sp.	n/a	n/a	<96hrs (4d)	Non-patent, displacement
88	No growth	*Bacillus* sp.	No growth	-Gm- nonfermenter - A-hemolytic *Strep*	96 hrs (4d)	Lameness
124	No growth	n/a	n/a	- *Bacillus* sp. - Coag neg *Staph*	<48hr (2d)	Non-patent, displacement
132	No growth	n/a	n/a	*Enterococcus* sp.	<48hr (2d)	Non-patent
87	No growth	n/a	n/a	No growth	<24hr (1d)	Non-patent
7	No growth	n/a	n/a	n/a	24hr (1d)	Lameness, swelling

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